

SECTION 15990

TESTING, ADJUSTING, AND BALANCING

PART 1 - GENERAL

1.1 RELATED DOCUMENTS

- A. Drawings and general provisions of the Contract, including General and Supplementary Conditions apply to this Section.

1.2 SUMMARY

- A. This Section includes testing, adjusting, and balancing HVAC systems to produce design objectives, including the following:
 - 1. Balancing airflow and water flow within complete distribution systems, including sub-mains, branches, and terminals, to indicated quantities on contract documents according to specified tolerances.
 - 2. Adjusting total HVAC systems to provide indicated quantities.
 - 3. Measuring electrical performance of HVAC equipment.
 - 4. Setting quantitative performance of HVAC equipment.
 - 5. Verifying that automatic control devices are functioning properly.
 - 6. Measuring sound and vibration.
 - 7. Reporting results of the activities and procedures specified in this Section.
- B. Related Sections include the following:
 - 1. Testing and adjusting requirements unique to particular systems and equipment are included in the Sections that specify those systems and equipment.
 - 2. Field quality control testing to verify that workmanship quality for system and equipment installation is specified in system and equipment Sections.

1.3 DEFINITIONS

- A. Adjust: To regulate fluid flow rate and air patterns at the terminal equipment, such as to reduce fan speed or adjust a damper.
- B. Balance: To proportion flows within the distribution system, including sub mains, branches, and terminals, according to design quantities.
- C. Draft: A current of air, when referring to localized effect caused by one or more factors of high air velocity, low ambient temperature, or direction of airflow, whereby more heat is withdrawn from a person's skin than is normally dissipated.
- D. Procedure: An approach to and execution of a sequence of work operations to yield repeatable results.
- E. Report Forms: Test data sheets for recording test data in logical order.
- F. Static Head: The pressure due to the weight of the fluid above the point of measurement. In a closed system, static head is equal on both sides of the pump.
- G. Suction Head: The height of fluid surface above the centerline of the pump on the suction side.
- H. System Effect: A phenomenon that can create undesired or unpredicted conditions that cause reduced capacities in all or part of a system.

- I. System Effect Factors: Allowances used to calculate a reduction of the performance ratings of a fan when installed under conditions different from those presented when the fan was performance tested.
- J. Terminal: A point where the controlled medium, such as fluid or energy, enters or leaves the distribution system.
- K. Test: A procedure to determine quantitative performance of a system or equipment.
- L. Testing, Adjusting, and Balancing Agent: The independent entity responsible for performing and reporting the testing, adjusting, and balancing procedures.
- M. AABC: Associated Air Balance Council.
- N. AMCA: Air Movement and Control Association.
- O. CTI: Cooling Tower Institute.
- P. NEBB: National Environmental Balancing Bureau.
- Q. SMACNA: Sheet Metal and Air Conditioning Contractors' National Association.

1.4 SUBMITTALS

- A. Quality-Assurance Submittals: Within 30 days from the Contractor's Notice to Proceed, submit 2 copies of evidence that the testing, adjusting, and balancing Agent and this Project's testing, adjusting, and balancing team members meet the qualifications specified in the "Quality Assurance" Article below.
- B. Certified Testing, Adjusting, and Balancing Reports: Submit 2 copies of reports prepared, as specified in this Section, on approved forms certified by the testing, adjusting, and balancing Agent.
- C. Warranty: Submit 4 copies of special warranty specified in the "Warranty" Article below.

1.5 QUALITY ASSURANCE

- A. Agent Qualifications: Engage a testing, adjusting, and balancing agent certified by either AABC or NEBB.
- B. Testing, Adjusting, and Balancing Conference: Meet with the Construction Manager's representatives on approval of the testing, adjusting, and balancing strategies and procedures plan to develop a mutual understanding of the details. Ensure the participation of testing; adjusting, and balancing team members, equipment manufacturers' authorized service representatives, HVAC controls Installer, and other support personnel. Provide 7 days' advance notice to Construction Manager of scheduled meeting time and location.
 - 1. Agenda Items: Include at least the following:
 - a. Submittal distribution requirements.
 - b. Contract Documents examination report.
 - c. Testing, adjusting, and balancing plan.
 - d. Work schedule and Project site access requirements.
 - e. Coordination and cooperation of trades and subcontractors.
 - f. Coordination of documentation and communication flow.
- C. Certification of Testing, Adjusting, and Balancing Reports: Certify the testing, adjusting, and balancing field data reports. This certification includes the following:

1. Review field data reports to validate accuracy of data and to prepare certified testing, adjusting, and balancing reports.
 2. Certify that the testing, adjusting, and balancing team complied with the approved testing, adjusting, and balancing plan and the procedures specified and referenced in this Specification.
- D. Testing, Adjusting, and Balancing Reports: Use standard forms from NEBB's "Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems."
- E. Testing, Adjusting, and Balancing Reports: Use standard forms from SMACNA's "HVAC Systems--Testing, Adjusting, and Balancing."
- F. Instrumentation Type, Quantity, and Accuracy: As described in NEBB's "Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems," Section II, "Required Instrumentation for NEBB Certification."
- G. Instrumentation Calibration: Calibrate instruments at least every 6 months or more frequently if required by the specific instrument manufacturer.

1.6 COORDINATION

- A. Coordinate the efforts of factory-authorized service representatives for systems and equipment, HVAC controls installers, and other mechanics to operate HVAC systems and equipment to support and assist testing, adjusting, and balancing activities.
- B. Notice: Provide 7 days' advance notice top Construction Manager for each test. Include scheduled test dates and times.
- C. Perform testing, adjusting, and balancing after leakage and pressure tests on air and water distribution systems have been satisfactorily completed.

1.7 WARRANTY

- A. Special Guarantee: Provide a guarantee on NEBB forms stating that NEBB will assist in completing the requirements of the Contract Documents if the testing, adjusting, and balancing Agent fails to comply with the Contract Documents. Guarantee includes the following provisions:
1. The certified Agent has tested and balanced systems according to the Contract Documents.
 2. Systems are balanced to optimum performance capabilities within design and installation limits.

PART 2 - PRODUCTS (Not Applicable)

PART 3 - EXECUTION

3.1 EXAMINATION

- A. Examine Contract Documents to become familiar with project requirements and to discover conditions in systems' designs that may preclude proper testing, adjusting, and balancing of systems and equipment.
1. Contract Documents are defined in the General and Supplementary Conditions of the Contract.
 2. Verify that balancing devices, such as test ports, gage cocks, thermometer wells, flow-control devices, balancing valves and fittings, and manual volume dampers, are required by the Contract Documents. Verify that quantities and locations of these balancing

devices are accessible and appropriate for effective balancing and for efficient system and equipment operation.

- B. Examine approved submittal data of HVAC systems and equipment.
- C. Examine project record documents described in General and Supplementary Conditions.
- D. Examine Architect's and Engineer's design data, including HVAC system descriptions, statements of design assumptions for environmental conditions and systems' output, and statements of philosophies and assumptions about HVAC system and equipment controls.
- E. Examine equipment performance data, including fan and pump curves. Relate performance data to project conditions and requirements, including system effects that can create undesired or unpredicted conditions that cause reduced capacities in all or part of a system. Calculate system effect factors to reduce the performance ratings of HVAC equipment when installed under conditions different from those presented when the equipment was performance tested at the factory. To calculate system effects for air systems, use tables and charts found in AMCA 201, "Fans and Systems," Sections 7 through 10; or in SMACNA's "HVAC Systems-Duct Design," Sections 5 and 6. Compare this data with the design data and installed conditions.
- F. Examine system and equipment installations to verify that they are complete and that testing, cleaning, adjusting, and commissioning specified in individual Specification Sections have been performed.
- G. Examine system and equipment test reports.
- H. Examine HVAC system and equipment installations to verify that indicated balancing devices, such as test ports, gage cocks, thermometer wells, flow-control devices, balancing valves and fittings, and manual volume dampers, are properly installed, and their locations are accessible and appropriate for effective balancing and for efficient system and equipment operation.
- I. Examine systems for functional deficiencies that cannot be corrected by adjusting and balancing.
- J. Examine air-handling equipment to ensure clean filters have been installed, bearings are greased, belts are aligned and tight, and equipment with functioning controls is ready for operation.
- K. Examine terminal units, such as variable-air-volume boxes and mixing boxes, to verify that they are accessible and their controls are connected and functioning.
- L. Examine plenum ceilings, utilized for supply air, to verify that they are airtight. Verify that pipe penetrations and other holes are sealed.
- M. Examine strainers for clean screens and proper perforations.
- N. Examine 3way valves for proper installation for their intended function of diverting or mixing fluid flows.
- O. Examine heat-transfer coils for correct piping connections and for clean and straight fins.
- P. Examine open-piping-system pumps to ensure absence of entrained air in the suction piping.
- Q. Examine equipment for installation and for properly operating safety interlocks and controls.

- R. Examine automatic temperature system components to verify the following:
 - 1. Dampers, valves, and other controlled devices operate by the intended controller.
 - 2. Dampers and valves are in the position indicated by the controller.
 - 3. Integrity of valves and dampers for free and full operation and for tightness of fully closed and fully open positions. This includes dampers in multizone units, mixing boxes, and variable-air-volume terminals.
 - 4. Automatic modulating and shutoff valves, including 2-way valves and 3-way mixing and diverting valves, are properly connected.
 - 5. Thermostats and humidistats are located to avoid adverse effects of sunlight, drafts, and cold walls.
 - 6. Sensors are located to sense only the intended conditions.
 - 7. Sequence of operation for control modes is according to the Contract Documents.
 - 8. Controller set points are set at design values. Observe and record system reactions to changes in conditions. Record default set points if different from design values.
 - 9. Interlocked systems are operating.
 - 10. Changeover from heating to cooling mode occurs according to design values.
- S. Report deficiencies discovered before and during performance of testing, adjusting, and balancing procedures.

3.2 PREPARATION

- A. Prepare a testing, adjusting, and balancing plan that includes strategies and step-by-step procedures.
- B. Complete system readiness checks and prepare system readiness reports. Verify the following:
 - 1. Permanent electrical power wiring is complete.
 - 2. Hydronic systems are filled, clean, and free of air.
 - 3. Automatic temperature-control systems are operational.
 - 4. Equipment and duct access doors are securely closed.
 - 5. Balance, smoke, and fire dampers are open.
 - 6. Isolating and balancing valves are open and control valves are operational.
 - 7. Ceilings are installed in critical areas where air-pattern adjustments are required and access to balancing devices is provided.
 - 8. Windows and doors can be closed so design conditions for system operations can be met.

3.3 GENERAL TESTING AND BALANCING PROCEDURES

- A. Perform testing and balancing procedures on each system according to the procedures contained in NEBB's "Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems" and this Section.
- B. Cut insulation, ducts, pipes, and equipment cabinets for installation of test probes to the minimum extent necessary to allow adequate performance of procedures. After testing and balancing, close probe holes and patch insulation with new materials identical to those removed. Restore vapor barrier and finish according to the insulation Specifications for this Project.
- C. Mark equipment settings with paint or other suitable, permanent identification material, including damper-control positions, valve indicators, fan-speed-control levers, and similar controls and devices, to show final settings.

3.4 FUNDAMENTAL AIR SYSTEMS' BALANCING PROCEDURES

- A. Prepare test reports for both fans and outlets. Obtain manufacturer's outlet factors and recommended testing procedures. Crosscheck the summation of required outlet volumes with required fan volumes.
- B. Prepare schematic diagrams of systems' "as-built" duct layouts.
- C. For variable-air-volume systems, develop a plan to simulate diversity.
- D. Determine the best locations in main and branch ducts for accurate duct airflow measurements.
- E. Check the airflow patterns from the outside-air louvers and dampers and the return- and exhaust-air dampers, through the supply-fan discharge and mixing dampers.
- F. Locate start-stop and disconnect switches, electrical interlocks, and motor starters.
- G. Verify that motor starters are equipped with properly sized thermal protection.
- H. Check dampers for proper position to achieve desired airflow path.
- I. Check for airflow blockages.
- J. Check condensate drains for proper connections and functioning.
- K. Check for proper sealing of air-handling unit components.

3.5 CONSTANT-VOLUME AIR SYSTEMS' BALANCING PROCEDURES

- A. The procedures in this Article apply to constant-volume supply-, return-, and exhaust-air systems. Additional procedures are required for variable-air-volume, multizone, dual-duct, induction-unit supply-air systems and process exhaust-air systems. These additional procedures are specified in other articles in this Section.
- B. Adjust fans to deliver total design airflows within the maximum allowable rpm listed by the fan manufacturer.
 - 1. Measure fan static pressures to determine actual static pressure as follows:
 - a. Measure outlet static pressure as far downstream from the fan as practicable and upstream from restrictions in ducts such as elbows and transitions.
 - b. Measure static pressure directly at the fan outlet or through the flexible connection.
 - c. Measure inlet static pressure of single-inlet fans in the inlet duct as near the fan as possible, upstream from flexible connection and downstream from duct restrictions.
 - d. Measure inlet static pressure of double-inlet fans through the wall of the plenum that houses the fan.
 - 2. Measure static pressure across each air-handling unit component.
 - a. Simulate dirty filter operation and record the point at which maintenance personnel must change filters.
 - 3. Measure static pressures entering and leaving other devices such as sound traps, heat recovery equipment, and air washers under final balanced conditions.
 - 4. Compare design data with installed conditions to determine variations in design static pressures versus actual static pressures. Compare actual system effect factors with calculated system effect factors to identify where substantial variations occur. Recommend corrective action to align design and actual conditions.

5. Adjust fan speed higher or lower to meet design conditions with available equipment adjustments. Do not make costly/major adjustments to pulley sizes, motor sizes, and electrical connections to accommodate fan-speed changes without prior approval from general contract manager or his appointed representative.
6. Do not make fan-speed adjustments that result in motor overload. Consult equipment manufacturers about fan-speed safety factors. Modulate dampers and measure fan-motor amperage to ensure no overload will occur. Measure amperage in full cooling, full heating, and economizer modes to determine the maximum required brake horsepower.

3.6 VARIABLE-AIR-VOLUME SYSTEMS' ADDITIONAL PROCEDURES

- A. Compensating for Diversity: When the total airflow of all terminal units is more than the fan design airflow volume, place a selected number of terminal units at a maximum set-point airflow condition until the total airflow of the terminal units equals the design airflow of the fan. Select the reduced airflow terminal units so they are distributed evenly among the branch ducts.
- B. Pressure-Dependent, Variable-Air-Volume Systems without Diversity: After the fan systems have been adjusted, adjust the variable-air-volume systems as follows:
 1. Balance systems similar to constant-volume air systems.
 2. Set terminal units and supply fan at full-airflow condition.
 3. Adjust inlet dampers of each terminal unit to design airflow and verify operation of the static-pressure controller. When total airflow is correct, balance the air outlets downstream from terminal units as described for constant-volume air systems.
 4. Readjust fan airflow for final maximum readings.
 5. Measure operating static pressure at the sensor that controls the supply fan, if one is installed, and verify operation of the static-pressure controller.
 6. Set supply fan at minimum airflow if minimum airflow is indicated. Measure static pressure to verify that the controller is maintaining it.
 7. Set terminal units at minimum airflow and adjust controller or regulator to deliver the designed minimum airflow. Check air outlets for a proportional reduction in airflow as described for constant-volume air systems.
 - a. If air outlets are out of balance at minimum airflow, report the condition but leave the outlets balanced for maximum airflow.
 8. Measure the return airflow to the fan while operating at maximum return airflow and minimum outside airflow. Adjust the fan and balance the return-air ducts and inlets as described for constant-volume air systems.
- C. Pressure-Dependent, Variable-Air-Volume Systems with Diversity: After the fan systems have been adjusted, adjust the variable-air-volume systems as follows:
 1. Set system at maximum design airflow by setting the required number of terminal units at minimum airflow. Select the reduced airflow terminal units so they are distributed evenly among the branch ducts.
 2. Adjust supply fan to maximum design airflow with the variable-airflow controller set at maximum airflow.
 3. Set terminal units being tested at full-airflow condition.
 4. Adjust terminal units starting at the supply-fan end of the system and continuing progressively to the end of the system. Adjust inlet dampers of each terminal unit to design airflow. When total airflow is correct, balance the air outlets downstream from terminal units as described for constant-volume air systems.
 5. Adjust terminal units for minimum airflow.
 6. Measure static pressure at the sensor.
 7. Measure the return airflow to the fan while operating at maximum return airflow and minimum outside airflow. Adjust the fan and balance the return-air ducts and inlets as described for constant-volume air systems.

3.7 FUNDAMENTAL PROCEDURES FOR HYDRONIC SYSTEMS

- A. Prepare test reports with pertinent design data and number in sequence starting at pump to end of system. Check the sum of branch-circuit flows against approved pump flow rate. Correct variations that exceed plus or minus 5 percent.
- B. Prepare schematic diagrams of systems' "as-built" piping layouts.
- C. Prepare hydronic systems for testing and balancing according to the following, in addition to the general preparation procedures specified above:
 - 1. Open all manual valves for maximum flow.
 - 2. Check expansion tank liquid level.
 - 3. Check makeup-water-station pressure gage for adequate pressure for highest vent.
 - 4. Check flow-control valves for specified sequence of operation and set at design flow.
 - 5. Set differential-pressure control valves at the specified differential pressure. Do not set at fully closed position when pump is positive-displacement type, unless several terminal valves are kept open.
 - 6. Set system controls so automatic valves are wide open to heat exchangers.
 - 7. Check pump-motor load. If motor is overloaded, throttle main flow-balancing device so motor nameplate rating is not exceeded.
 - 8. Check air vents for a forceful liquid flow exiting from vents when manually operated.

3.8 HYDRONIC SYSTEMS' BALANCING PROCEDURES

- A. Determine water flow at pumps. Use the following procedures, except for positive-displacement pumps:
 - 1. Verify impeller size by operating the pump with the discharge valve closed. Verify with the pump manufacturer that this will not damage pump. Read pressure differential across the pump. Convert pressure to head and correct for differences in gage heights. Note the point on the manufacturer's pump curve at zero flow and confirm that the pump has the intended impeller size.
 - 2. Check system resistance. With all valves open, read pressure differential across the pump and mark the pump manufacturer's head-capacity curve. Adjust pump discharge valve until design water flow is achieved.
 - 3. Verify pump-motor brake horsepower. Calculate the intended brake horsepower for the system based on the pump manufacturer's performance data. Compare calculated brake horsepower with nameplate data on the pump motor. Report conditions where actual amperage exceeds motor nameplate amperage.
 - 4. Report flow rates that are not within plus or minus 5 percent of design.
- B. Set calibrated balancing valves, if installed, at calculated presetting.
- C. Measure flow at all stations and adjust, where necessary, to obtain first balance.
 - 1. System components that have Cv rating or an accurately cataloged flow-pressure-drop relationship may be used as a flow-indicating device.
- D. Measure flow at main balancing station and set main balancing device to achieve flow that is 5 percent greater than design flow.
- E. Adjust balancing stations to within specified tolerances of design flow rate as follows:
 - 1. Determine the balancing station with the highest percentage over design flow.
 - 2. Adjust each station in turn, beginning with the station with the highest percentage over design flow and proceeding to the station with the lowest percentage over design flow.
 - 3. Record settings and mark balancing devices.

- F. Measure pump flow rate and make final measurements of pump amperage, voltage, rpm, pump heads, and systems' pressures and temperatures, including outdoor-air temperature.
- G. Measure the differential-pressure control valve settings existing at the conclusions of balancing.

3.9 VARIABLE-FLOW HYDRONIC SYSTEMS' ADDITIONAL PROCEDURES

- A. Balance systems with automatic 2- and 3-way control valves by setting systems at maximum flow through heat-exchange terminals and proceed as specified above for hydronic systems.

3.10 PRIMARY-SECONDARY-FLOW HYDRONIC SYSTEMS' ADDITIONAL PROCEDURES

- A. Balance the primary system crossover flow first, and then balance the secondary system.

3.11 HEAT EXCHANGERS

- A. Measure and record the following data with each heat exchanger operating at design conditions:
 - 1. Measure water flow through all circuits.
 - 2. Adjust water flow to within specified tolerances.
 - 3. Measure inlet and outlet water temperatures.
 - 4. Measure inlet steam pressure. Check the setting and operation of automatic temperature-control valves, self-contained control valves, and pressure-reducing valves.
 - 5. Record safety valve settings.
 - 6. Verify operation of steam traps.

3.12 MOTORS

- A. Motors, 1/2 HP and Larger: Test at final balanced conditions and record the following data:
 - 1. Manufacturer, model, and serial numbers.
 - 2. Motor horsepower rating.
 - 3. Motor rpm.
 - 4. Efficiency rating if high-efficiency motor.
 - 5. Nameplate and measured voltage, each phase.
 - 6. Nameplate and measured amperage, each phase.
 - 7. Starter thermal-protection-element rating.
- B. Motors Driven by Variable-Frequency Controllers: Test for proper operation at speeds varying from minimum to maximum. Test the manual bypass for the controller to prove proper operation. Record observations, including controller manufacturer, model and serial numbers, and nameplate data.

3.13 CHILLERS

- A. Balance water flow through each evaporator and condenser to within specified tolerances of design flow with all pumps operating. With only one chiller operating in a multiple chiller installation, do not exceed the flow for the maximum tube velocity recommended by the chiller manufacturer. Measure and record the following data with each chiller operating at design conditions:
 - 1. Evaporator water entering and leaving temperatures, pressure drop, and water flow.
 - 2. Condenser water entering and leaving temperatures, pressure drop, and water flow.
 - 3. Evaporator and condenser refrigerant temperatures and pressures, using instruments furnished by the chiller manufacturer.
 - 4. Power factor if factory-installed instrumentation is furnished for measuring kW.
 - 5. The kW input if factory-installed instrumentation is furnished for measuring kW.

6. Capacity: Calculate in tons of cooling.
7. Air-Cooled Chillers: Verify condenser-fan rotation and record fan data, including number of fans and entering- and leaving-air temperatures.

3.14 COOLING TOWERS

- A. Shut off makeup water for the duration of the test, and then make sure the makeup and blow-down systems are fully operational after tests and before leaving the equipment. Perform the following tests and record the results:
 1. Measure condenser water flow to each cell of the cooling tower.
 2. Measure entering- and leaving-water temperatures.
 3. Measure wet- and dry-bulb temperatures of entering air.
 4. Measure wet- and dry-bulb temperatures of leaving air.
 5. Measure condenser water flow rate re-circulating through the cooling tower.
 6. Measure cooling tower pump discharge pressure.
 7. Adjust water level and feed rate of makeup-water system.

3.15 BOILERS

- A. Measure entering- and leaving-water temperatures and water flow.

3.16 HEAT-TRANSFER COILS

- A. Water Coils: Measure the following data for each coil:
 1. Entering- and leaving-water temperatures.
 2. Water flow rate.
 3. Water pressure drop.
 4. Dry-bulb temperatures of entering and leaving air.
 5. Wet-bulb temperatures of entering and leaving air for cooling coils designed for less than 7,500 cfm (1,275 M³/Hr).
 6. Airflow.
 7. Air pressure drop.
- B. Electric-Heating Coils: Measure the following data for each coil:
 1. Nameplate data.
 2. Airflow.
 3. Entering- and leaving-air temperatures at full load.
 4. Voltage and amperage input of each phase at full load and at each incremental stage.
 5. Calculated kW at full load.
 6. Fuse or circuit breaker rating for overload protection.

3.17 TEMPERATURE TESTING

- A. During testing, adjusting, and balancing, report need for adjustment in temperature regulation within the automatic temperature-control system.
- B. Measure indoor wet- and dry-bulb temperatures every other hour for a period of 2 successive 8-hour days, in each separately controlled zone, to prove correctness of final temperature settings. Measure when the building or zone is occupied.
- C. Measure outside-air, wet- and dry-bulb temperatures.

3.18 FUME HOODS

- A. Determine total airflow into the room where the fume hood is located and balance systems to ensure adequate air supply to all hoods.

1. Set fume-hood door opening at position of normal use.
2. Energize the exhaust fan and adjust airflow to provide the indicated average fume-hood face velocity at hood opening.
3. Measure exhausts airflow volume by measuring airflow by Pitot-tube duct traverse.
4. Measure air velocity using Pitot-tube traverse method.
5. Record each face velocity measurement taken at 4- to 6-inch (100- to 150-mm) increments over the entire hood door opening.
6. Calculate the average face velocity by averaging all velocity measurements.
7. Calculate the airflow volume of exhaust-hood face velocity by multiplying the calculated average face velocity by the opening area. Compare this quantity with exhaust volume at exhaust fan and report duct leakage.
8. Measure airflow volume supplied by makeup fan. Verify that the makeup system supplies the proper amount of air to keep the space at the indicated pressure with the exhaust systems in all operating conditions.
9. Retest for average face velocity. Adjust hood baffles, fan drives, and other parts of the system to provide the indicated average face velocity and the indicated auxiliary air-supply percentages.
10. Retest and adjust the systems until fume-hood performance complies with Contract Documents.

3.19 TEMPERATURE-CONTROL VERIFICATION

- A. Verify that controllers are calibrated and commissioned.
- B. Check transmitter and controller locations and note conditions that would adversely affect control functions.
- C. Record controller settings and note variances between set points and actual measurements.
- D. Verify operation of limiting controllers (i.e., high- and low-temperature controllers).
- E. Verify free travel and proper operation of control devices such as damper and valve operators.
- F. Verify sequence of operation of control devices. Note air pressures and device positions and correlate with airflow and water-flow measurements. Note the speed of response to input changes.
- G. Confirm interaction of electrically operated switch transducers.
- H. Confirm interaction of interlock and lockout systems.
- I. Verify main control supply-air pressure and observe compressor and dryer operations.
- J. Record voltages of power supply and controller output. Determine if the system operates on a grounded or not-grounded power supply.
- K. Note operation of electric actuators using spring return for proper fail-safe operations.

3.20 TOLERANCES

- A. Set HVAC system airflow and water flow rates within the following tolerances:
 1. Supply, Return, and Exhaust Fans: Plus 5 to plus 10 percent.
 2. Air Outlets and Inlets: 0 to minus 10 percent.
 3. Heating-Water Flow Rate: 0 to minus 5 percent.
 4. Cooling-Water Flow Rate: 0 to minus 5 percent.

3.21 REPORTING

- A. Initial Construction-Phase Report: Based on examination of the Contract Documents as specified in "Examination" Article above, prepare a report on the adequacy of design for systems' balancing devices. Recommend changes and additions to systems' balancing devices to facilitate proper performance measuring and balancing. Recommend changes and additions to HVAC systems and general construction to allow access for performance measuring and balancing devices.
- B. Status Reports: As Work progresses, prepare reports to describe completed procedures, procedures in progress, and scheduled procedures. Include a list of deficiencies and problems found in systems being tested and balanced. Prepare a separate report for each system and each building floor for systems serving multiple floors.

3.22 FINAL REPORT

- A. General: Typewritten, or computer printout in letter-quality font, on standard bond paper, in 3-ring binder, tabulated and divided into sections by tested and balanced systems.
- B. Include a certification sheet in front of binder signed and sealed by the certified testing and balancing engineer.
 - 1. Include a list of the instruments used for procedures, along with proof of calibration.
- C. Final Report Contents: In addition to the certified field report data, include the following:
 - 1. Pump curves.
 - 2. Fan curves.
 - 3. Manufacturers' test data.
 - 4. Field test reports prepared by system and equipment installers.
 - 5. Other information relative to equipment performance, but do not include approved Shop Drawings and Product Data.
- D. General Report Data: In addition to the form titles and entries, include the following data in the final report, as applicable:
 - 1. Title page.
 - 2. Name and address of testing, adjusting, and balancing Agent.
 - 3. Project name.
 - 4. Project location.
 - 5. Architect/Engineer's name and address.
 - 6. Contractor's name and address.
 - 7. Report date.
 - 8. Signature of testing, adjusting, and balancing Agent who certifies the report.
 - 9. Summary of contents, including the following:
 - a. Design versus final performance.
 - b. Notable characteristics of systems.
 - c. Description of system operation sequence if it varies from the Contract Documents.
 - 10. Nomenclature sheets for each item of equipment if it varies from the Contract Document.
 - 11. Data for terminal units, including manufacturer, type size, and fittings.
 - 12. Notes to explain why certain final data in the body of reports vary from design values.
 - 13. Test conditions for fans and pump performance forms, including the following:
 - a. Settings for outside-, return-, and exhaust-air dampers.
 - b. Conditions of filters.
 - c. Cooling coil, wet- and dry-bulb conditions.
 - d. Face and bypass damper settings at coils.
 - e. Fan drive settings, including settings and percentage of maximum pitch diameter.
 - f. Inlet vane settings for variable-air-volume systems.

- g. Settings for supply-air, static-pressure controller.
 - h. Other system operating conditions that affect performance.
- E. System Diagrams: Include schematic layouts of air and hydronic distribution systems. Present with single-line diagrams and include the following:
 - 1. Quantities of outside, supply, return, and exhaust airflows.
 - 2. Water flow rates.
 - 3. Duct, outlet, and inlet sizes.
 - 4. Pipe and valve sizes and locations.
 - 5. Terminal units.
 - 6. Balancing stations.
- F. Air-Handling Unit Test Reports: For air-handling units with coils, include the following:
 - 1. Unit Data: Include the following:
 - a. Unit identification.
 - b. Location.
 - c. Make and type.
 - d. Model number and unit size.
 - e. Manufacturer's serial number.
 - f. Unit arrangement and class.
 - g. Discharge arrangement.
 - h. Sheave make, size in inches (mm), and bore.
 - i. Sheave dimensions, center-to-center and adjustment amounts in inches (mm).
 - j. Number of belts, make, and size.
 - k. Number of filters, type, and size.
 - 2. Motor Data: Include the following:
 - a. Make and frame type and size.
 - b. Horsepower and rpm.
 - c. Volts, phase, and hertz.
 - d. Full-load amperage and service factor.
 - e. Sheave make, size in inches (mm), and bore.
 - f. Sheave dimensions, center-to-center and adjustment amounts in inches (mm).
 - 3. Test Data: Include design and actual values for the following:
 - a. Total airflow rate in cfm (M^3/Hr).
 - b. Total system static pressure in inches wg (Pa).
 - c. Fan rpm.
 - d. Discharge static pressure in inches wg (Pa).
 - e. Filter static pressure differential in inches wg (Pa).
 - f. Preheat coil static-pressure differential in inches wg (Pa).
 - g. Cooling coil static-pressure differential in inches wg (Pa).
 - h. Heating coil static-pressure differential in inches wg (Pa).
 - i. Outside airflow in cfm (M^3/Hr).
 - j. Return airflow in cfm (M^3/Hr).
 - k. Outside-air damper position.
 - l. Return-air damper position.
 - m. Vortex damper position.
- G. Apparatus-Coil Test Reports: For apparatus coils, include the following:
 - 1. Coil Data: Include the following:
 - a. System identification.
 - b. Location.
 - c. Coil type.
 - d. Number of rows.
 - e. Fin spacing in fins per inch (mm o.c.).
 - f. Make and model number.
 - g. Face area in sq. ft. (sq. m).
 - h. Tube size in NPS (DN).

- i. Tube and fin materials.
 - j. Circuiting arrangement.
 2. Test Data: Include design and actual values for the following:
 - a. Airflow rate in **cfm** (M^3/Hr).
 - b. Average face velocity in **fpm** (m/s).
 - c. Air pressure drop in **inches wg** (Pa).
 - d. Outside-air, wet- and dry-bulb temperatures in **deg F** (deg C).
 - e. Return-air, wet- and dry-bulb temperatures in **deg F** (deg C).
 - f. Entering-air, wet- and dry-bulb temperatures in **deg F** (deg C).
 - g. Leaving-air, wet- and dry-bulb temperatures in **deg F** (deg C).
 - h. Water flow rate in **gpm** (L/s).
 - i. Water pressure differential in **feet of head or psig** (kPa).
 - j. Entering-water temperature in **deg F** (deg C).
 - k. Leaving-water temperature in **deg F** (deg C).
 - l. Refrigerant expansion valve and refrigerant types.
 - m. Refrigerant suction pressure in **psig** (kPa).
 - n. Refrigerant suction temperature in **deg F** (deg C).
 - o. Inlet steam pressure in **psig** (kPa).
- H. Gas- and Oil-Fired Heat Apparatus Test Reports: In addition to the manufacturer's factory startup equipment reports, include the following:
 1. Unit Data: Include the following:
 - a. System identification.
 - b. Location.
 - c. Make and type.
 - d. Model number and unit size.
 - e. Manufacturer's serial number.
 - f. Fuel type in input data.
 - g. Output capacity in **Btu/Hr** (kW).
 - h. Ignition type.
 - i. Burner-control types.
 - j. Motor horsepower and rpm.
 - k. Motor volts, phase, and hertz.
 - l. Motor full-load amperage and service factor.
 - m. Sheave make, size in inches (mm), and bore.
 - n. Sheave dimensions, center-to-center and adjustment amounts in inches (mm).
 2. Test Data: Include design and actual values for the following:
 - a. Total airflow rate in **cfm** (M^3/Hr).
 - b. Entering-air temperature in **deg F** (deg C).
 - c. Leaving-air temperature in **deg F** (deg C).
 - d. Air temperature differential in **deg F** (deg C).
 - e. Entering-air static pressure in **inches wg** (Pa).
 - f. Leaving-air static pressure in **inches wg** (Pa).
 - g. Air static pressure differential in **inches wg** (Pa).
 - h. Low-fire fuel input in **Btu/Hr** (kW).
 - i. High-fire fuel input in **Btu/Hr** (kW).
 - j. Manifold pressure in **psig** (kPa).
 - k. High-temperature-limit setting in **deg F** (deg C).
 - l. Operating set point in **Btu/Hr** (kW).
 - m. Motor voltage at each connection.
 - n. Motor amperage for each phase.
 - o. Heating value of fuel in **Btu/Hr** (kW).
- I. Electric-Coil Test Reports: For electric furnaces, duct coils, and electric coils installed in central-station air-handling units, include the following:
 1. Unit Data: Include the following:
 - a. System identification.

- b. Location.
 - c. Coil identification.
 - d. Capacity in **Btu/Hr (kW)**.
 - e. Number of stages.
 - f. Connected volts, phase, and hertz.
 - g. Rated amperage.
 - h. Airflow rate in **cfm (M³/Hr)**.
 - i. Face area in **sq. ft. (sq. m)**.
 - j. Minimum face velocity in **fpm (m/s)**.
 2. Test Data: Include design and actual values for the following:
 - a. Heat output in **Btu/Hr (kW)**.
 - b. Airflow rate in **cfm (M³/Hr)**.
 - c. Air velocity in **fpm (m/s)**.
 - d. Entering-air temperature in **deg F (deg C)**.
 - e. Leaving-air temperature in **deg F (deg C)**.
 - f. Voltage at each connection.
 - g. Amperage for each phase.
- J. Fan Test Reports: For supply, return, and exhaust fans, include the following:
 1. Fan Data: Include the following:
 - a. System identification.
 - b. Location.
 - c. Make and type.
 - d. Model number and size.
 - e. Manufacturer's serial number.
 - f. Arrangement and class.
 - g. Sheave make, size in **inches (mm)**, and bore.
 - h. Sheave dimensions, center-to-center and adjustment amounts in **inches (mm)**.
 2. Motor Data: Include the following:
 - a. Make and frame type and size.
 - b. Horsepower and rpm.
 - c. Volts, phase, and hertz.
 - d. Full-load amperage and service factor.
 - e. Sheave make, size in **inches (mm)**, and bore.
 - f. Sheave dimensions, center-to-center and adjustment amounts in **inches (mm)**.
 - g. Number of belts, make, and size.
 3. Test Data: Include design and actual values for the following:
 - a. Total airflow rate in **cfm (M³/Hr)**.
 - b. Total system static pressure in **inches wg (Pa)**.
 - c. Fan rpm.
 - d. Discharge static pressure in **inches wg (Pa)**.
 - e. Suction static pressure in **inches wg (Pa)**.
- K. Round, Flat-Oval, and Rectangular Duct Traverse Reports: Include a diagram with a grid representing the duct cross-section and record the following:
 1. Report Data: Include the following:
 - a. System and air-handling unit number.
 - b. Location and zone.
 - c. Traverse air temperature in **deg F (deg C)**.
 - d. Duct static pressure in **inches wg (Pa)**.
 - e. Duct size in **inches (mm)**.
 - f. Duct area in **sq. ft. (sq. m)**.
 - g. Design airflow rate in **cfm (M³/Hr)**.
 - h. Design velocity in **fpm (m/s)**.
 - i. Actual airflow rate in **cfm (M³/Hr)**.
 - j. Actual average velocity in **fpm (m/s)**.
 - k. Barometric pressure in **psig (Pa)**.

- L. Air-Terminal-Device Reports: For terminal units, include the following:
1. Unit Data: Include the following:
 - a. System and air-handling unit identification.
 - b. Location and zone.
 - c. Test apparatus used.
 - d. Area being served.
 - e. Air-terminal-device makes.
 - f. Air-terminal-device number from system diagram.
 - g. Air-terminal-device type and model number.
 - h. Air-terminal-device size.
 - i. Air-terminal-device effective area in sq. ft. (sq. m).
 2. Test Data: Include design and actual values for the following:
 - a. Airflow rate in cfm (M³/Hr).
 - b. Air velocity in fpm (m/s).
 - c. Preliminary airflow rate as needed in cfm (M³/Hr).
 - d. Preliminary velocity as needed in fpm (m/s).
 - e. Final airflow rate in cfm (M³/Hr).
 - f. Final velocity in fpm (m/s).
 - g. Space temperature in deg F (deg C).
- M. System-Coil Reports: For reheat coils and water coils of terminal units, include the following:
1. Unit Data: Include the following:
 - a. System and air-handling unit identification.
 - b. Location and zone.
 - c. Room or riser served.
 - d. Coil make and size.
 - e. Flow meter type.
 2. Test Data: Include design and actual values for the following:
 - a. Airflow rate in cfm (M³/Hr).
 - b. Entering-water temperature in deg F (deg C).
 - c. Leaving-water temperature in deg F (deg C).
 - d. Water pressure drop in feet of head or psig (kPa).
 - e. Entering-air temperature in deg F (deg C).
 - f. Leaving-air temperature in deg F (deg C).
- N. Packaged Chiller Reports: For each chiller, include the following:
1. Unit Data: Include the following:
 - a. Unit identification.
 - b. Make and model number.
 - c. Manufacturer's serial number.
 - d. Refrigerant type and capacity in gal. (L).
 - e. Starter type and size.
 - f. Starter thermal protection size.
 2. Condenser Test Data: Include design and actual values for the following:
 - a. Refrigerant pressure in psig (kPa).
 - b. Refrigerant temperature in deg F (deg C).
 - c. Entering-water temperature in deg F (deg C).
 - d. Leaving-water temperature in deg F (deg C).
 - e. Entering-water pressure in feet of head or psig (kPa).
 - f. Water pressure differential in feet of head or psig (kPa).
 3. Evaporator Test Reports: Include design and actual values for the following:
 - a. Refrigerant pressure in psig (kPa).
 - b. Refrigerant temperature in deg F (deg C).
 - c. Entering-water temperature in deg F (deg C).
 - d. Leaving-water temperature in deg F (deg C).
 - e. Entering-water pressure in feet of head or psig (kPa).
 - f. Water pressure differential in feet of head or psig (kPa).

4. Compressor Test Data: Include design and actual values for the following:
 - a. Make and model number.
 - b. Manufacturer's serial number.
 - c. Suction pressure in psig (kPa).
 - d. Suction temperature in deg F (deg C).
 - e. Discharge pressure in psig (kPa).
 - f. Discharge temperature in deg F (deg C).
 - g. Oil pressure in psig (kPa).
 - h. Oil temperature in deg F (deg C).
 - i. Voltage at each connection.
 - j. Amperage for each phase.
 - k. The kW input.
 - l. Crankcase heater kW.
 - m. Chilled water control set point in deg F (deg C).
 - n. Condenser water control set point in deg F (deg C).
 - o. Refrigerant low-pressure-cutoff set point in psig (kPa).
 - p. Refrigerant high-pressure-cutoff set point in psig (kPa).
 5. Refrigerant Test Data: Include design and actual values for the following:
 - a. Oil level.
 - b. Refrigerant level.
 - c. Relief valve setting in psig (kPa).
 - d. Unloader set points in psig (kPa).
 - e. Percentage of cylinders unloaded.
 - f. Bearing temperatures in deg F (deg C).
 - g. Vane position.
 - h. Low-temperature-cutoff set point in deg F (deg C).
- O. Compressor and Condenser Reports: For refrigerant side of unitary systems, stand-alone refrigerant compressors, air-cooled condensing units, or water-cooled condensing units, include the following:
1. Unit Data: Include the following:
 - a. Unit identification.
 - b. Location.
 - c. Unit make and model number.
 - d. Manufacturer's compressor serial numbers.
 - e. Compressor make.
 - f. Compressor model and serial numbers.
 - g. Refrigerant weight in lb (kg).
 - h. Low ambient temperature cutoff in deg F (deg C).
 2. Test Data: Include design and actual values for the following:
 - a. Inlet-duct static pressure in inches wg (Pa).
 - b. Outlet-duct static pressure in inches wg (Pa).
 - c. Entering-air, dry-bulb temperature in deg F (deg C).
 - d. Leaving-air, dry-bulb temperature in deg F (deg C).
 - e. Condenser entering-water temperature in deg F (deg C).
 - f. Condenser leaving-water temperature in deg F (deg C).
 - g. Condenser water temperature differential in deg F (deg C).
 - h. Condenser entering-water pressure in feet of head or psig (kPa).
 - i. Condenser leaving-water pressure in feet of head or psig (kPa).
 - j. Condenser water pressure differential in feet of head or psig (kPa).
 - k. Control settings.
 - l. Unloader set points.
 - m. Low-pressure-cutout set point in psig (kPa).
 - n. High-pressure-cutout set point in psig (kPa).
 - o. Suction pressure in psig (kPa).
 - p. Suction temperature in deg F (deg C).
 - q. Condenser refrigerant pressure in psig (kPa).

- r. Condenser refrigerant temperature in deg F (deg C).
 - s. Oil pressure in psig (kPa).
 - t. Oil temperature in deg F (deg C).
 - u. Voltage at each connection.
 - v. Amperage for each phase.
 - w. The kW input.
 - x. Crankcase heater kW.
 - y. Number of fans.
 - z. Condenser fan rpm.
 - aa. Condenser fan airflow rate in cfm (M^3/Hr).
 - bb. Condenser fan motor make, frame size, rpm, and horsepower.
 - cc. Condenser fan motor voltage at each connection.
 - dd. Condenser fan motor amperage for each phase.
- P. Cooling Tower or Condenser Test Reports: For cooling towers or condensers, include the following:
- 1. Unit Data: Include the following:
 - a. Unit identification.
 - b. Make and type.
 - c. Model and serial numbers.
 - d. Nominal cooling capacity in tons (kW).
 - e. Refrigerant type and weight in lb (kg).
 - f. Water-treatment chemical feeder and chemical.
 - g. Number and type of fans.
 - h. Fan motor make, frame size, rpm, and horsepower.
 - i. Fan motor voltage at each connection.
 - j. Sheave make, size in inches (mm), and bore.
 - k. Sheave dimensions, center-to-center and adjustment amounts in inches (mm).
 - l. Number of belts, make, and size.
 - 2. Pump Test Data: Include design and actual values for the following:
 - a. Make and model number.
 - b. Manufacturer's serial number.
 - c. Motor make and frame size.
 - d. Motor horsepower and rpm.
 - e. Voltage at each connection.
 - f. Amperage for each phase.
 - g. Water flow rate in gpm (L/s).
 - 3. Water Test Data: Include design and actual values for the following:
 - a. Entering-water temperature in deg F (deg C).
 - b. Leaving-water temperature in deg F (deg C).
 - c. Water temperature differential in deg F (deg C).
 - d. Entering-water pressure in feet of head or psig (kPa).
 - e. Leaving-water pressure in feet of head or psig (kPa).
 - f. Water pressure differential in feet of head or psig (kPa).
 - g. Water flow rate in gpm (L/s).
 - h. Bleed water flow rate in gpm (L/s).
 - 4. Air Data: Include design and actual values for the following:
 - a. Duct airflow rate in cfm (M^3/Hr).
 - b. Inlet-duct static pressure in inches wg (Pa).
 - c. Outlet-duct static pressure in inches wg (Pa).
 - d. Average entering-air, wet-bulb temperature in deg F (deg C).
 - e. Average leaving-air, wet-bulb temperature in deg F (deg C).
 - f. Ambient wet-bulb temperature in deg F (deg C).

- Q. Heat-Exchanger/Converter Test Reports: For water to water heat exchangers, include the following:

- 1. Unit Data: Include the following:

- a. Unit identification.
 - b. Location.
 - c. Service.
 - d. Make and type.
 - e. Model and serial numbers.
 - f. Ratings.
 2. Water Test Data: Include design and actual values for the following:
 - a. Inlet pressures in psig (kPa).
 - b. Water flow rates in lb/h (kW).
 3. Primary Water Test Data: Include design and actual values for the following:
 - a. Entering-water temperature in deg F (deg C).
 - b. Leaving-water temperature in deg F (deg C).
 - c. Entering-water pressure in feet of head or psig (kPa).
 - d. Water pressure differential in feet of head or psig (kPa).
 - e. Water flow rate in gpm (L/s).
 4. Secondary Water Test Data: Include design and actual values for the following:
 - a. Entering-water temperature in deg F (deg C).
 - b. Leaving-water temperature in deg F (deg C).
 - c. Entering-water pressure in feet of head or psig (kPa).
 - d. Water pressure differential in feet of head or psig (kPa).
 - e. Water flow rate in gpm (L/s).
- R. Pump Test Reports: For pumps, include the following data. Calculate impeller size by plotting the shutoff head on pump curves.
 1. Unit Data: Include the following:
 - a. Unit identification.
 - b. Location.
 - c. Service.
 - d. Make and size.
 - e. Model and serial numbers.
 - f. Water flow rate in gpm (L/s).
 - g. Water pressure differential in feet of head or psig (kPa).
 - h. Required net positive suction head in feet of head or psig (kPa).
 - i. Pump rpm.
 - j. Impeller diameter in inches (mm).
 - k. Motor make and frame size.
 - l. Motor horsepower and rpm.
 - m. Voltage at each connection.
 - n. Amperage for each phase.
 - o. Full-load amperage and service factor.
 - p. Seal type.
 2. Test Data: Include design and actual values for the following:
 - a. Static head in feet of head or psig (kPa).
 - b. Pump shutoff pressure in feet of head or psig (kPa).
 - c. Actual impeller size in inches (mm).
 - d. Full-open flow rate in gpm (L/s).
 - e. Full-open pressure in feet of head or psig (kPa).
 - f. Final discharge pressure in feet of head or psig (kPa).
 - g. Final suction pressure in feet of head or psig (kPa).
 - h. Final total pressure in feet of head or psig (kPa).
 - i. Final water flow rate in gpm (L/s).
 - j. Voltage at each connection.
 - k. Amperage for each phase.
- S. Instrument Calibration Reports: For instrument calibration, include the following:
 1. Report Data: Include the following:
 - a. Instrument type and make.

- b. Serial number.
- c. Application.
- d. Dates of use.
- e. Dates of calibration.

3.23 ADDITIONAL TESTS

- A. Within 90 days of completing testing, adjusting, and balancing, perform additional testing and balancing to verify that balanced conditions are being maintained throughout and to correct unusual conditions.
- B. Seasonal Periods: If initial testing, adjusting, and balancing procedures were not performed during near-peak summer and winter conditions, perform additional inspections, testing, and adjusting during near-peak summer and winter conditions.

END OF SECTION 15990